REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 0704-0188*

1. AGENCY USE ONLY *(Leave blank)*	**2. REPORT DATE** 23.Jun.03	**3. REPORT TYPE AND DATES COVERED** THESIS

4. TITLE AND SUBTITLE "CEREBRAL OXYGEN SATURATION AS A PREDICTOR OF IMENDING GRAVITY INDUCED LOSS OF CONSCIOUSNESS(GLOC)"	**5. FUNDING NUMBERS**
6. AUTHOR(S) MAJ BORCHARDT CHRISTOPHER J	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) UNIVERSITY OF TEXAS HSC AT HOUSTON	**8. PERFORMING ORGANIZATION REPORT NUMBER** CI02-984
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) THE DEPARTMENT OF THE AIR FORCE AFIT/CIA, BLDG 125 2950 P STREET WPAFB OH 45433	**10. SPONSORING/MONITORING AGENCY REPORT NUMBER**
11. SUPPLEMENTARY NOTES	
12a. DISTRIBUTION AVAILABILITY STATEMENT Unlimited distribution In Accordance With AFI 35-205/AFIT Sup 1	**12b. DISTRIBUTION CODE**

13. ABSTRACT *(Maximum 200 words)*

20030714 152

14. SUBJECT TERMS			**15. NUMBER OF PAGES** 34
			16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT	**18. SECURITY CLASSIFICATION OF THIS PAGE**	**19. SECURITY CLASSIFICATION OF ABSTRACT**	**20. LIMITATION OF ABSTRACT**

CEREBRAL OXYGEN SATURATION AS A PREDICTOR OF IMPENDING GRAVITY INDUCED LOSS OF CONSCIOUSNESS (GLOC)

By

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APPROVED:

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CEREBRAL OXYGEN SATURATION AS A PREDICTOR OF IMPENDING GRAVITY INDUCED LOSS OF CONSCIOUSNESS (GLOC)

By

CHRISTOPHER J. BORCHARDT, MD

THESIS

Presented to the Faculty of The University of Texas

Health Science Center at Houston

School of Public Health

in Partial Fulfillment

of the Requirements

for the Degree of

MASTER OF PUBLIC HEALTH

THE UNIVERSITY OF TEXAS HEALTH SCIENCE CENTER AT HOUSTON
SCHOOL OF PUBLIC HEALTH
Houston, Texas
August, 2003

ACKNOWLEDGMENTS

I, as a researcher and aviator, am indebted to the United States Air Force members who volunteer to participate in centrifuge research requiring them to endure extreme physical forces and phenomena. Their contributions are critical to the development of life saving and performance enhancing advances that ensure the safety and effectiveness of our aviators.

My sincere thanks go to Lloyd Tripp and Chuck Goodyear at the Air Force Research Laboratory at Wright-Patterson Air Force Base for their support, insight, and guidance. I am also thankful for the focus provided by Dr. Alfonso Holguin and Dr. William Spears as members of my master's thesis committee.

Thesis submitted to the M.P.H. Committee on April 2, 2003.

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INTRODUCTION

Aerospace medicine has been challenged by the phenomena of Gz induced Loss Of Consciousness (GLOC) since as early as World War I when pilots described "fainting" while pulling out of dives during aerial combat (1). Gz is the force of gravity holding us to the ground, but pilots are exposed to forces considerably in excess of the 1 Gz that is experienced when simply standing on the ground. As an aircraft pitches to change direction, as in a loop or steep turn, additional Gz is experienced that crushes a pilot into the cockpit seat. This is similar to the forces experienced during sharp turns in a car or rollercoaster, only significantly stronger due to the high speeds of flight. 2 Gz represents a doubling of the force of gravity, while 9 Gz effectively multiplies a pilot's body weight by nine. Current fighter aircraft are capable of reaching and sustaining 9 Gz for short periods of time. High +Gz forces cause pooling of blood in the lower extremities and deviation of internal organs downward into the seat. When too much blood is drawn away from the head by high Gz the brain can run low on oxygen resulting in the phenomena known as GLOC.

During the intervening years between WWI and now a considerable amount of effort and resources has gone into developing protective life support equipment and pilot performed anti-Gz straining maneuvers to avoid GLOC. This effort has been necessary to keep up with the ever-improving performance of fighter aircraft currently in use. High performance aircraft currently in the USAF inventory include the F-16 and F-15, which are capable of sustaining 6-7 +Gz with peaks to 9 +Gz being possible. Since GLOC continues to occur today, and a possibility of even

higher performance aircraft being deployed in the future exists, it is important to examine additional methods of avoiding GLOC. In-flight physiologic monitoring has been considered, but not examined to date, which is why this study is an important step in that direction.

Methods that have been significantly researched and proven in operational use include centrifuge training, weight training, the anti-G suit, positive pressure breathing, postural modifications in the cockpit, and anti-G straining maneuvers, all of which are targeted at enhancing a pilot's Gz tolerance. The two most recent advances include the Combined Advanced Technology Enhanced Designed G-Ensemble (COMBAT EDGE) and the Advanced Technology Anti-G-Suit (ATAGS). COMBAT EDGE combines Positive Pressure Breathing (PPB) and a chest counter-pressure vest to avoid over inflation due to the PPB. Worn with the standard G-suit, COMBAT EDGE increases G tolerance by about 2 Gs (2). ATAGS is an enhanced coverage garment, which provides 90% below the waist coverage. The standard G-suit increases G tolerance by 1.0 to 1.5 G and ATAGS increases it by an additional 0.5 to 1.0 G (3,4).

Even with these advances GLOC continues to be a major physiologic threat to aircrew of high-performance aircraft. GLOC has been present since the earliest fighter aircraft where flown in 1919. Since the mid 1980s, 29 aircraft and 22 pilots have been lost, due to GLOC, by the USAF alone. GLOC is the USAF Air Combat Command's second most frequently occurring human factor problem and is a continual concern during mission planning, training, and execution (5).

GLOC poses an interesting challenge in that developing protection is not as easily quantifiable as producing suits for protection against temperature, pressure, and radiation extremes. While these other factors have a measurable quantity of danger that can be mitigated through measurable degrees of protection, GLOC offers no such variables. Anti-G suit and anti-G straining protection offer an improvement from baseline Gz tolerance, but that improvement varies between pilots and is not readily measured. High-performance USAF pilots must demonstrate the ability to tolerate a 9 +Gz exposure in a human centrifuge prior to being trained and assigned to an operational fighter unit, but that only demonstrates that on that given day they were adequately hydrated, sufficiently rested, and adequately prepared and protected to avoid GLOC during that exposure. It is evident from the continued occurrence of GLOC that this onetime checkout is not a guarantee of future successful avoidance.

A method of continual monitoring with appropriate feedback would clearly be beneficial to the high-performance pilot community. This would provide the quantifiable piece of protection that is currently missing from the GLOC equation. This study examined cerebral tissue oxygenation (rSO2) levels at baseline and at the time of GLOC in an effort to provide a consistent measurable value to predict and ultimately avoid GLOC. Cerebral tissue oxygenation was chosen because the requirements of advanced neurosurgical techniques have resulted in the development and validation of an rSO2 measurement device that is accurate and small enough to be unobtrusively incorporated into existing fighter helmets. If this

study demonstrates specific amounts of decrease in rSO2 to be a consistent GLOC predictor between multiple subjects then it would justify further human centrifuge studies with a larger number of subjects.

Previous research has provided extensive knowledge regarding the characteristics of GLOC. The focus of the majority of this work was on preventing GLOC through the development and refinement of the anti-G suit and anti-G straining technology and techniques which continue toward the development of a full body anti-G suit (6-9). Another focus was to reduce the periods of absolute (complete unconsciousness) and relative incapacitation (confusion and disorientation) following GLOC (10-12). While improving protection and reducing the negative aftereffects of GLOC continue to show promising advances, the approaches are currently limited by increasingly cumbersome personal equipment or complex aircraft technology required to perform maneuvers autonomously after a pilot experience a GLOC. The promise of rSO2, or another easily monitored physiologic factor, is that the equipment would be unobtrusive, simple, and the pilot would still ultimately be in command to react to or ignore the impending GLOC indication. The previously mentioned techniques of shortening GLOC duration involves the aircraft detecting that a GLOC has occurred and maneuvers are initiated as an override to the pilot's inputs. This system of taking over for the pilot would not be well received, as demonstrated by the USAF's experience with the automatic terrain avoidance system, and could potentially be inappropriately

triggered in the absence of a GLOC during a critical phase of flight thus placing the pilot in a compromised if not dangerous situation.

The choice of rSO2 for this study stems from the extensive research that suggests a hypoxic mechanism for GLOC resulting from ischemia due to pooling of blood in the gravity dependant extremities and lower abdomen (9-13). Important factors such as the relationship between the magnitude of hypoxic exposure and the degree of incapacitation (9), along with reduction in recovery time as a result of rapid reduction of +Gz exposure (11), all suggest hypoxia and thus rSO2 as the primary determinant of the occurrence and duration of GLOC.

The rSO2 data were collected in the original USAF study utilizing the Somanetics INVOS 4100 Cerebral Oximeter. This device employs the noninvasive near infrared spectroscopy (NIR) technique to measure rSO2. This technique is used extensively to measure cellular oxygen metabolism and oxygen delivery to tissues. NIR has been validated and described extensively by Norris (14) and Jobsis (15). Dujovny et al reported an average rSO2 in 100 randomly selected subjects as 68.8% +/- 5.6% (16). Since the cerebral oximeter is a noninvasive proven design it is ideally suited to incorporation into a helmet without causing significant distraction to pilots.

Cerebral oximetry works due to the spectral absorption characteristics of oxygenated hemoglobin (HbO2) and reduced hemoglobin (Hb) that differ from 600nm to 110nm respectively. The relationship of absorption and attenuation is described by the Beer-Lambert Law and is utilized to calculate rSO2. A sensor is

placed on the subject's forehead that transmits the NIR photons into the cranium at specific wavelengths. The wavelengths were chosen because of their ability to traverse through skin, bone, and brain tissue. The light scatters and reflects through the tissues with some returning to the sensor. The sensor measures the intensity of the returning light which is used determine the rSO2.

To insure that the value returned by the sensor is actually cerebral oxygen saturation (rSO2) as opposed to a composite of all the tissues the light has passed through, a double detector system is employed. A shallow and deep detector each measure light return from superficial layers i.e. skin, skull and dura, and deep cerebral tissue respectively. The instrument can then accurately determine cerebral oxygenation by removing the shallow component leaving only the deep component. Cui, et al, validated this approach and demonstrated its accuracy through their independent study (17). The rSO2 as measured by the oximeter represents blood in the following approximate proportions by volume; venous 75%, arterial 20%, and capillary 5%.

Independent investigators have tested the INVOS 4100 under known hypoxic conditions and demonstrated that the device was sufficiently responsive and accurate to measure rapid changes in tissue oxygen saturation as would be expected to occur in human centrifuge studies or operational high-performance aircraft (18,19). Another study has demonstrated a decrease in cerebral blood volume and cerebral oxyhemoglobin during sustained +Gz acceleration further confirming the premise of this study (20). Operational cerebral oxygen status data is

limited to a single study of F-15 aircrew that demonstrated reductions in hemoglobin concentration of between 12.8 to 25.6 micro-mol/L of brain tissue (21).

This study is meant to address the knowledge gap that exists regarding rSO2 and GLOC by determining if a consistent relationship exists within and between human subjects exposed to GLOC in a USAF centrifuge facility. Identifying a consistent relationship could lead to the development of a GLOC avoidance indicator, while lack of a relationship would allow research efforts to be directed toward identification of a valid predictor of impending GLOC.

MATERIALS AND METHODS

Subjects

An original study titled "Gravity Induced Loss of Consciousness (GLOC) Less than 1 Gz Recovery" was reviewed and approved by the Air Force Research Laboratory (AFRL) Institutional Review Board (IRB) and the Air Force Surgeon General. Lloyd D. Tripp, who is a research scientist at AFRL, was the primary investigator and granted permission to use the cerebral oxygenation (rSO2) portion of the original study's dataset for this research paper. Human centrifuge GLOC research is not routinely conducted due to the expense, immense logistics, and physical stress placed on the human participants, therefore a great deal of instrumentation is attached in excess of what is specifically required for the intended research. This practice allows for analysis and correlation of many physical variables that may not have been a primary focus without exposing human subjects to additional high Gz stress and unconsciousness.

The original study focused on cognitive task performance during recovery from GLOC and any differences in recovery time or performance associated with applying negative Gz, essentially turning the subjects upside-down, immediately following GLOC. This was done to determine if automated aircraft maneuvers designed to rapidly return blood to the brain following GLOC could reduce a pilot's recovery time. The required data consisted of tracking and cognitive tasks simulating fighter pilot workload, and manually recorded time of unconsciousness for comparison between positive and negative Gz recoveries.

Additional instrumentation, not required for the original study, consisted of EEG, EKG, finger pulse oximetry, expiratory CO2, and cerebral tissue oximetry (rSO2). The rSO2 data was analyzed for this study. No prior analysis of this type exists for the rSO2 data set.

Study participants were active duty USAF volunteers who were trained members of the AFRL Sustained Acceleration Stress Panel. Members of this panel are screened for musculoskeletal, cardiac, pulmonary, and metabolic disqualifying conditions. Physical standards, with the exception of visual acuity, in excess of the Flying Class 1 aircrew standards are applied to these panel members ensuring their safety and ability to represent the pilot population. Informed consent regarding participation in GLOC studies was obtained prior to participation. Subject age ranged from 25 to 36 y/o with a mean of 29 y/o. The dataset is free of any unique identifiers.

Facilities

The human use centrifuge utilized for the study is at Wright-Patterson Air Force Base (WPAFB). The facility is known as the Dynamic Environment Simulator (DES) due to its ability to create positive, negative, and lateral accelerations. The DES is pictured in Figure 1. The interior of the DES is equipped with an ACES II ejection seat (inert) that is reclined 30 degrees in an identical configuration to F-16 aircraft. Padded head restraints were added to the seat to prevent lateral head movement during GLOC while the reclined angle assists in avoiding a forward head drop. An F-16 flight control stick was used to perform tracking and mathematical

tasks simulating the demanding flight environment. The seat and stick configuration is pictured in Figure 2. The necessary visuals were produced by an INFOCUS 630 projection system directed at a screen approximately five feet in front of the participants. An emergency break switch is kept in the subject's left hand to allow for rapidly stopping the centrifuge if necessary.

The subjects were monitored via infrared camera, cerebral oximeter, pulse oximeter, electrocardiogram, and electroencephalogram. Data were collected and recorded in real-time for several studies that were occurring concurrently.

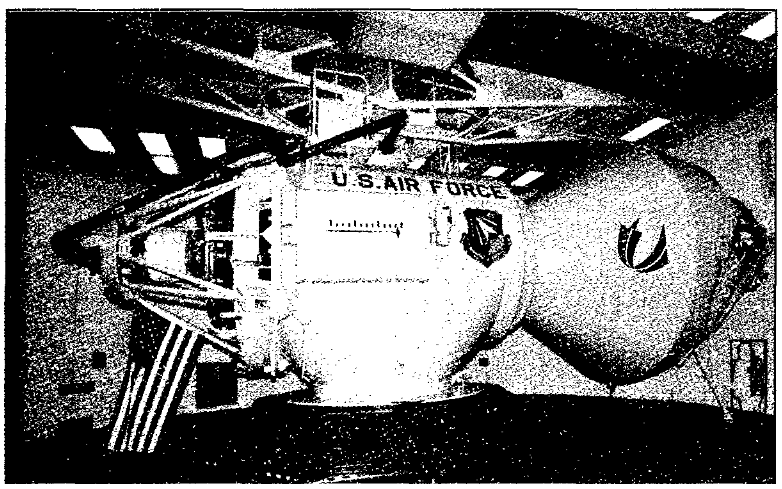

Figure 1 Dynamic Environment Simulator (DES) Wright-Patterson AFB, OH

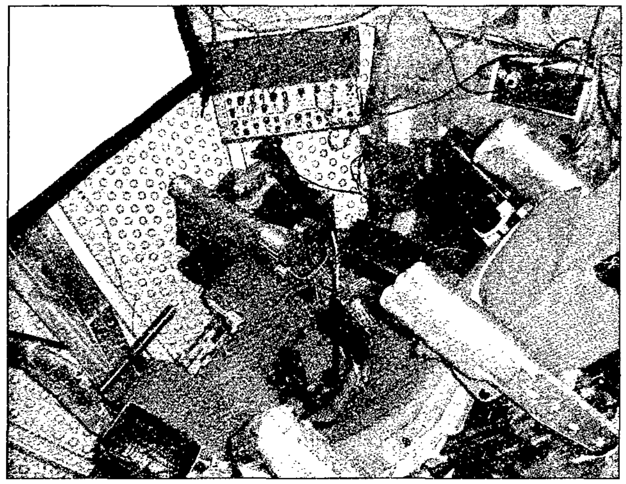

Figure 2 Centrifuge cab configuration with aircraft seat

Subject Preparation

The study that produced this dataset required the performance of neurocognitive tasks prior to and following GLOC. Task training took place for 30 minutes at a time on four separate days. Additional training was added if error rates between two consecutive days differed by greater than 10% indicating that the subjects had not reached a consistent level of performance.

On test days subjects were examined by a Flight Surgeon ensuring they were physically qualified as per AFRL standards. Monitoring instrumentation was then attached, including the Somanetics INVOS 4100 Cerebral Oximeter. The oximeter was placed immediately below the hairline and to the left of midline to avoid bony midline structures that could interfere with readings. A single individual was responsible for placement throughout the study in an effort to ensure consistency.

Subjects wore a standard flight suit and helmet without additional anti-G suit protection since GLOC was the desired outcome. Higher +Gz exposures would

have been required to achieve GLOC if additional anti-G protection had been utilized thus exposing subjects to more physical stress while unconscious.

+Gz Exposure Descriptions

Six subjects experienced three GLOCs events separated by at least 72 hours but not more than one week. Each centrifuge test day consisted of two high +Gz exposures. The first was a Gradual Onset Rate (GOR) tolerance profile. This profile identified the subject's relaxed +Gz tolerance and was used to determine the minimum level of +GZ exposure that would result in GLOC. The GOR profile accelerates at 0.1 Gz/sec while the subject focuses on a red circle projected on the screen. The circle is sized to represent a 10 degree visual field angle which provides an safe endpoint for the subject to identify as their visual fields are reduced to tunnel vision by the increasing +Gz. The centrifuge run is discontinued once the red circle is the only thing the subject can see. One +Gz is added to the level that the GOR run was discontinued to determine the level that will produce GLOC. The subject is then given a six-minute rest period to insure tissue oxygenation levels have returned to baseline. The second exposure was a Rapid Onset Rate (ROR) that accelerated at 3 +Gz/sec to the maximum level determined during the GOR run ending in GLOC. The ROR run was when data collection took place since it was the exposure that produced GLOC. A contingency plan of discontinuing the ROR run if GLOC had not occurred after 15 seconds at peak +Gz was in place for subject safety. If GLOC did not occur a rest period and a second ROR would be conducted with concurrence of the subject and medical monitor.

GLOC was identified by the principle investigator using the criteria proposed by Whinnery (7), which included slumping of the head and upper body, jaw relaxation as evidenced by gaping mouth, and eye closure as demonstrated in Figure 3. The principle investigator for this study had observed and experienced numerous GLOCs in the past resulting in the best possible degree of consistency.

Each GLOC was followed by a neurologic and physical exam no adverse outcomes were identified. Each GLOC exposure was separated by at least 72 hours but less than one week.

Figure 3 Air Force Research Laboratory stock photo demonstrating GLOC

Data Collection

The original study required six participants to experience three GLOCs. Only cerebral oxygenation (rSO2) data were used for analysis in this study, although EEG, EKG, pulse oximetry, and cognitive task data were recorded simultaneously. Formal permission to use the dataset, along with an acknowledgment that no personal identifiers were included, was obtained and is attached.

The dataset consists of cerebral oxygenation (rSO2) values obtained from the Somanetics INVOS 4100 Cerebral Oximeter, which represents the deep cerebral tissue level of oxygen saturation as a percentage of complete saturation after correction for superficial tissue interference. Data available includes baseline rSO2 prior to exposure, minimum rSO2 occurring at GLOC, maximum overshoot rSO2 following GLOC during the recovery period (a compensatory over-correction phenomena), and post recovery rSO2 baseline measured five minutes after GLOC to ensure normal saturation levels had returned prior to departing the facility. These data allow for the calculations necessary to determine if a consistent decrease in rSO2 prior to GLOC existed within and between subjects.

DATA ANALYSIS

Baseline and GLOC (min) rSO2 values, expressed as percent saturation, are provided in Table 1 and plotted in Chart 1 below. The final columns are the percent and absolute decrease in rSO2 from baseline to the minimum values obtained at GLOC. The average percent and absolute decrease is shown in bold at the bottom of the table.

Subject	Test Day	Base rSO2	min rSO2	%base rSO2	Abs diff
1	1	65.56	51.00	22.20	14.56
1	2	72.22	59.00	18.31	13.22
1	3	65.61	54.50	17.06	11.11
2	1	76.50	66.00	13.73	10.50
2	2	74.39	62.67	15.71	11.73
2	3	72.67	63.67	12.38	9.00
3	1	55.89	52.00	6.96	3.89
3	2	56.01	46.50	16.77	9.51
3	3	60.32	51.50	14.55	8.82
4	1	71.76	60.67	15.53	11.09
4	2	74.56	67.33	9.70	7.23
4	3	69.11	58.50	15.35	10.61
5	1	76.39	59.34	22.35	17.06
5	2	72.40	60.67	16.20	11.73
5	3	70.85	62.50	11.61	8.35
6	1	59.00	51.33	13.00	7.67
6	2	56.91	47.67	16.31	9.25
6	3	61.35	54.84	10.75	6.52
			Mean	**14.91**	**10.1**

Table 1 rSO2 (% Cerebral Oxygen Saturation)

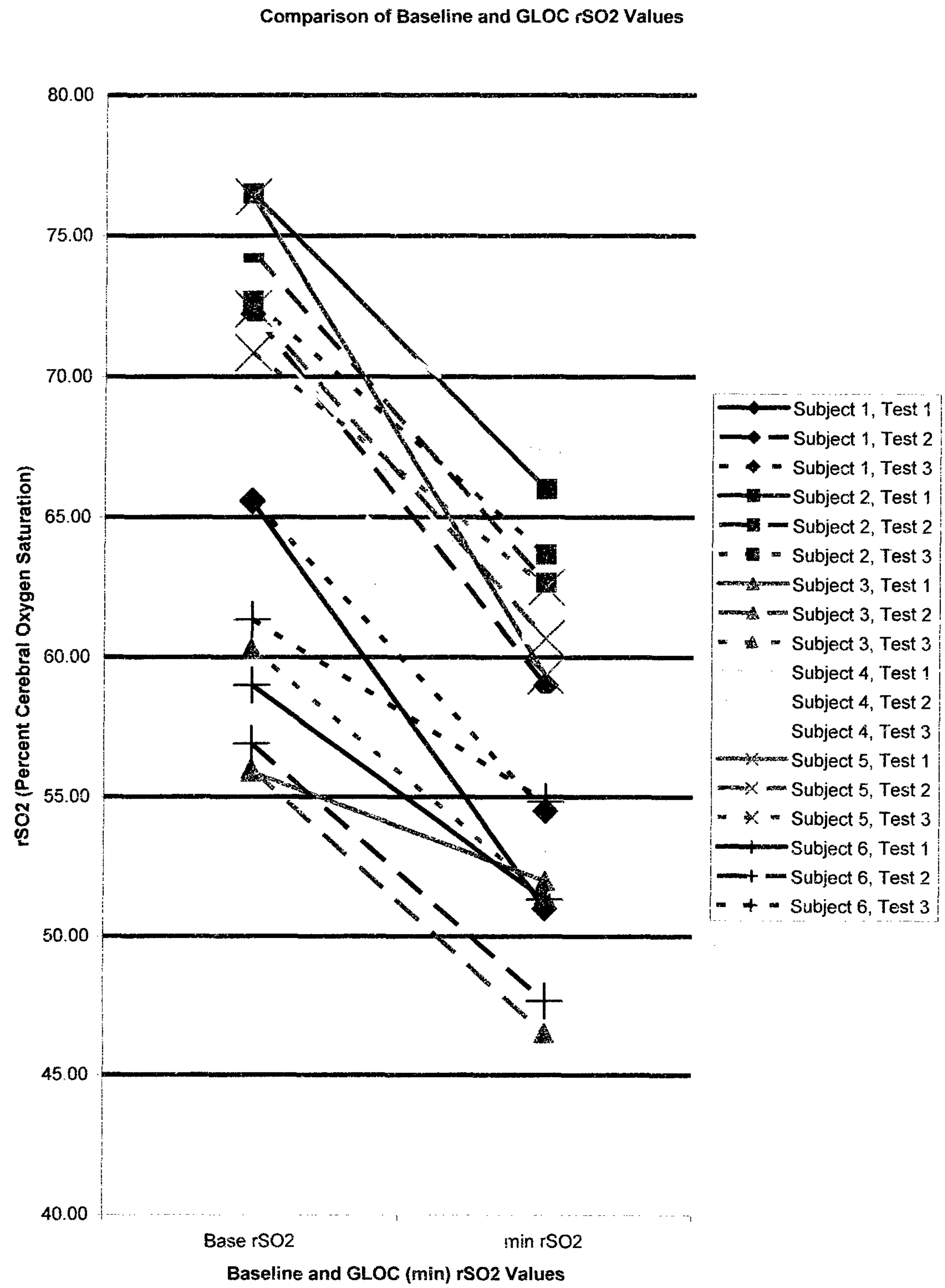

Figure 4 Comparison of Baseline and GLOC rSO2 Values

Visual analysis of Chart 1 indicates a consistent absolute decrease in rSO2 prior to GLOC for each subject on each of the test days. An ANOVA analysis calculation was used to statistically examine the data because of its ability to allocate the amount of variation in a process and determine if it is significant or is caused by random noise.

The ANOVA analysis of the data in Table 1 indicated that the baseline and minimum rSO2 values for each subject across each of the three test days did not differ significantly within subjects. The ANOVA of the baseline rSO2 data produced $F\,(2,10)=0.233$, $p>0.05$, while the ANOVA of the minimum rSO2 data points produced $F\,(2,10)=0.019$, $p>0.05$. These results mean that, taking each subject individually, the three baseline rSO2 values taken on each of the three test days showed no statistically significant variation ($p>0.05$). No variation of baseline rSO2 would be expected based on known physiology so this result indicates that the centrifuge or the subject's protective helmet did not interfere with the data collection equipment unpredictably.

Equally important is that no statistically significant variation ($p>0.05$) existed between each of the three test day's minimum rSO2 values for each subject. While the known physiology of GLOC suggests that this would be the case, it was the purpose of this study to determine whether or not that consistent relationship existed.

Since no statistical variation existed within each subject's baseline and minimum rSO2 data points it was possible to simplify the dataset to determine if a

statistically significant difference exists between baseline and minimum rSO2 for all of the subjects. Each subject's three baseline and minimum rSO2 values were averaged to produce a single baseline and minimum rSO2 value. The six subject's averaged baseline and minimum rSO2 values were then analyzed for differences using a Student T-Test.

The paired sample 2-Tailed T-Test of the averaged data points for baseline and minimum rSO2 values demonstrated a significant decrease in rSO2 immediately prior to GLOC, $t\,(5) = 10.814$, $p < 0.01$, paired samples correlation 0.963. This finding indicates that, for these six subjects, a measurable decrease in rSO2 existed that could be distinguished from random variation ($p<0.01$). This result is consistent with known GLOC physiology, and is a critical first step toward being able to predict and potentially avoid GLOC using physiologic monitoring.

DISCUSSION

This study's goal was to determine if a consistent relationship exists between cerebral oxygen saturation (rSO2) and GLOC. This knowledge is a critical first step toward development of an impending GLOC warning indicator that could be utilized in high performance aircraft to avoid a life threatening unconsciousness during high Gz maneuvers.

In this study the baseline rSO2 represents a pilot's cerebral oxygen saturation during straight and level flight while minimum rSO2 represents the lowest cerebral oxygen saturation, experienced during high Gz maneuvering, that the brain will tolerate prior to initiating a GLOC. To develop a viable impending GLOC indicator it is essential to demonstrate that baseline rSO2 is measurably consistent in flight and that a statistically significant difference exists between a measurably consistent minimum rSO2 experienced prior to GLOC.

The ANOVA analysis of the baseline and minimum rSO2 data from the six subjects demonstrated no significant difference within the three test days for each of the six subjects. This is the important step of demonstrating the consistency of the baseline and minimum rSO2 endpoints. If differences within subjects had existed that would have suggested an unacceptable degree of variability in the measured rSO2 making it an unreliable physiologic indicator. Norris (14), Jobsis (15), and Dujovny et. al. (16) have demonstrated that under ideal, non-hypoxic, conditions rSO2 will be consistent between test days within subjects, so a significant difference in this study's data would suggest that the measurement device did not function

correctly under high Gz stress and an alternative device would have to be found. Since the data did demonstrate consistency the Somanetics INVOS 4100 Cerebral Oximeter could be used during high Gz flight to monitor rSO2.

The relationship between rSO2 and GLOC was established by the significant difference between the baseline and minimum rSO2. A consistent significant difference has to be present for a warning indication to be meaningful. Chart 1 visually demonstrates the decrease in rSO2 prior to GLOC and also highlights that the slopes of the decrease are nearly identical. This is important because it indicates that an absolute decrease, 10.10 points on average, is observed prior to GLOC. Even though each subject had different initial baseline they each underwent a similar absolute decrease in rSO2, which greatly simplifies the process of predicting an impending GLOC. Regardless of baseline a similar decrease in rSO2 occurred prior to GLOC negating concerns regarding variations in skull or tissue thickness that could contribute to differences in baseline.

This study further reinforces the physiologic model of decreasing cerebral oxygenation resulting in GLOC developed by Whinnery (8,9). It also indicates that in-flight cerebral oxygenation (rSO2) monitoring to avoid GLOC is feasible using currently available technology. Further research would be necessary to verify that a consistent absolute decrease in rSO2 prior to GLOC occurs throughout the high performance pilot population, and that a warning could be provided that was effective without prohibiting necessary aggressive maneuvering. A follow-on study could focus on rSO2 trends during high Gz aggressive maneuvering as compared to

GLOC events to determine if a significant difference exists between minimum conscious maneuvering rSO2 levels and rSO2 occurring at GLOC.

Clearly high performance aviators would benefit from further research of this unique monitoring technology given the results produced by this study.

APPENDIX

THE UNIVERSITY of TEXAS
HEALTH SCIENCE CENTER AT HOUSTON
SCHOOL of PUBLIC HEALTH

Research Services Center
Phone 713.500.9055
Fax 713.500.9145

MEMORANDUM

TO: Christopher J. Borchardt

FROM: R. Sue Day, PhD
Associate Dean for Research

RE: Thesis Proposal

DATE: March 6, 2003

TITLE: Cerebral Oxygen Saturation as a Predictor of Impending GLOC

Your proposal has been reviewed and approved by the UT School of Public Health Research Services Center. Your proposal is exempt from review by the University of Texas Health Science Center at Houston Committee for the Protection of Human Subjects. You may proceed with your research.

CC: Dr. Alfonso H. Holguin
Sema Spigner, Student Affairs

Note: Other committee member(s) include Dr. William Spears

VERIDIAN
VERIDIAN ENGINEERING

MEMORANDUM

DATE: November 12, 2002

TO: Christopher J. Borchardt

FROM: Lloyd D. Tripp
Research Scientist
Veridian Engineering
5200 Springfield Pike
Dayton, OH 45431
(937) 255-4391

RE: Use of Data by Christopher J. Borchardt

I am granting permission for Dr. Christopher J. Borchardt to analyze data collected during project entitled "*Gravity Induced Loss of Consciousness (GLOC) Less than 1 Gz Recovery.*" Participants from this study are identified in the data set by subject number only and are not identified by name.

The data set to be used was collected with the approval of the Air Force Research Laboratory IRB and the final approval of the Air Force Surgeon General (See Attached Approval Letter). If you have any questions concerning this research please contact me at the number provided.

Sincerely

Lloyd D. Tripp

Lloyd D. Tripp
Research Scientist
Veridian Engineering

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